Math 1553
Introduction to Linear Algebra

School of Mathematics
Georgia Institute of Technology

Chapter 1

Overview

Linear. Algebra.

What is Linear Algebra?

Linear

- having to do with lines/planes/etc.
- For example, $x + y + 3z = 7$, not $\sin, \log, x^2$, etc.

Algebra

- solving equations involving numbers and symbols
- from al-jebr (Arabic), meaning reunion of broken parts
- 9^{th} century Abu Ja'far Muhammad ibn Muso al-Khwarizmi

Why a whole course?

But these are the easiest kind of equations! I learned how to solve them in 7th grade!

Ah, but engineers need to solve *lots* of equations in *lots* of variables.

$$\begin{aligned}
3x_1 + 4x_2 + 10x_3 + 19x_4 - 2x_5 - 3x_6 &= 141 \\
7x_1 + 2x_2 - 13x_3 - 7x_4 + 21x_5 + 8x_6 &= 2567 \\
-x_1 + 9x_2 + \tfrac{3}{2}x_3 + x_4 + 14x_5 + 27x_6 &= 26 \\
\tfrac{1}{2}x_1 + 4x_2 + 10x_3 + 11x_4 + 2x_5 + x_6 &= -15
\end{aligned}$$

Often, it's enough to know some information about the set of solutions without having to solve the equations at all!

Also, what if one of the coefficients of the x_i is itself a parameter— like an unknown real number t?

In real life, the difficult part is often in recognizing that a problem can be solved using linear algebra in the first place: need *conceptual* understanding.

Linear Algebra in Engineering

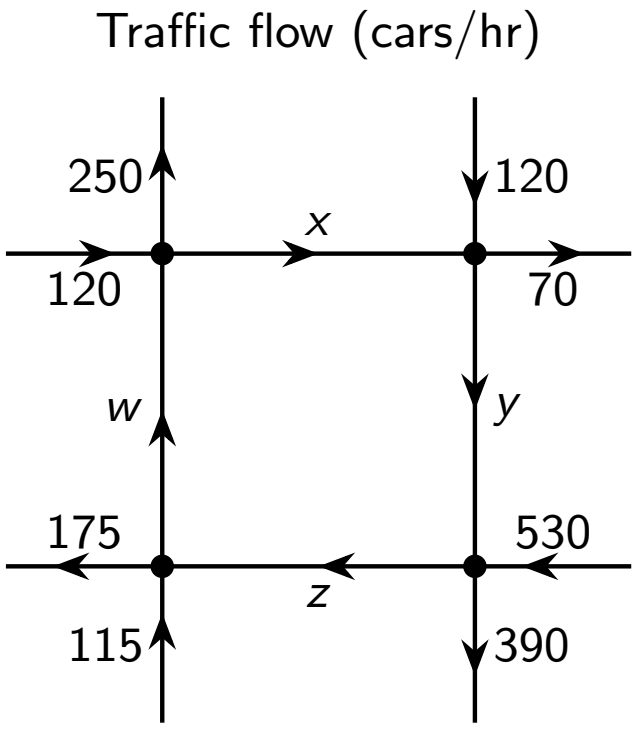
Large classes of engineering problems, no matter how huge, can be reduced to linear algebra:

$$Ax = b \quad \text{or}$$
$$Ax = \lambda x$$

"... and now it's just linear algebra"

Applications of Linear Algebra

Civil Engineering: How much traffic flows through the four labeled segments?



⇝ system of linear equations:

$$\begin{aligned} w + 120 &= x + 250 \\ x + 120 &= y + 70 \\ y + 530 &= z + 390 \\ z + 115 &= w + 175 \end{aligned}$$

Applications of Linear Algebra

Chemistry: Balancing reaction equations

$$\underline{\ x\ }\ C_2H_6 + \underline{\ y\ }\ O_2 \to \underline{\ z\ }\ CO_2 + \underline{\ w\ }\ H_2O$$

$\rightsquigarrow$ system of linear equations, one equation for each element.

$$\begin{aligned} 2x &= z \\ 6x &= 2w \\ 2y &= 2z + w \end{aligned}$$

Applications of Linear Algebra

Biology: In a population of rabbits. . .

- half of the new born rabbits survive their first year
- of those, half survive their second year
- the maximum life span is three years
- rabbits produce 0, 6, 8 rabbits in their first, second, and third years

If I know the population in 2016 (in terms of the number of first, second, and third year rabbits), then what is the population in 2017?

$\rightsquigarrow$ system of linear equations:

$$\begin{aligned} 6y_{2016} + 8z_{2016} &= x_{2017} \\ \tfrac{1}{2}x_{2016} &= y_{2017} \\ \tfrac{1}{2}y_{2016} &= z_{2017} \end{aligned}$$

Question

Does the rabbit population have an asymptotic behavior? Is this even a linear algebra question? Yes, it is! [interactive]

Applications of Linear Algebra

Geometry and Astronomy: Find the equation of a circle passing through 3 given points, say $(1,0)$, $(0,1)$, and $(1,1)$. The general form of a circle is $a(x^2+y^2)+bx+cy+d=0$.

$\rightsquigarrow$ system of linear equations:

$$\begin{aligned} a+b\quad\quad+d&=0\\ a\quad\quad+c+d&=0\\ 2a+b+c+d&=0 \end{aligned}$$

Very similar to: compute the orbit of a planet:

$$ax^2+by^2+cxy+dx+ey+f=0$$

Applications of Linear Algebra

Google: "The 25 billion dollar eigenvector." Each web page has some importance, which it shares via outgoing links to other pages

$\rightsquigarrow$ system of linear equations (in gazillions of variables).

Larry Page flies around in a private 747 because he paid attention in his linear algebra class!

Overview of the Course

- Solve the matrix equation $Ax = b$
  - Solve systems of linear equations using matrices, row reduction, and inverses.
  - Solve systems of linear equations with varying parameters using parametric forms for solutions, the geometry of linear transformations, the characterizations of invertible matrices, and determinants.

- Solve the matrix equation $Ax = \lambda x$
  - Solve eigenvalue problems through the use of the characteristic polynomial.
  - Understand the dynamics of a linear transformation via the computation of eigenvalues, eigenvectors, and diagonalization.

- Almost solve the equation $Ax = b$
  - Find best-fit solutions to systems of linear equations that have no actual solution using least squares approximations.

What to Expect This Semester

Your previous math courses probably focused on how to do (sometimes rather involved) computations.

- Compute the derivative of $\sin(\log x)\cos(e^x)$.
- Compute $\int_0^1 (1 - \cos(x))\,dx$.

This is important, **but** Matlab can do all these problems better than any of us can. Nobody is going to hire you to do something a computer can do better.

> If a computer can do the problem better than you can, then it's just an algorithm: **this is not problem solving**.

So what are we going to do?

- About half the material focuses on how to do linear algebra computations—that is still important.
- The other half is on *conceptual* understanding of linear algebra. This is much more subtle: it's about figuring out *what question* to ask the computer, or whether you actually need to do any computations at all.

Applications in Physics

Observables like position and momentum $\rightsquigarrow$ linear operators

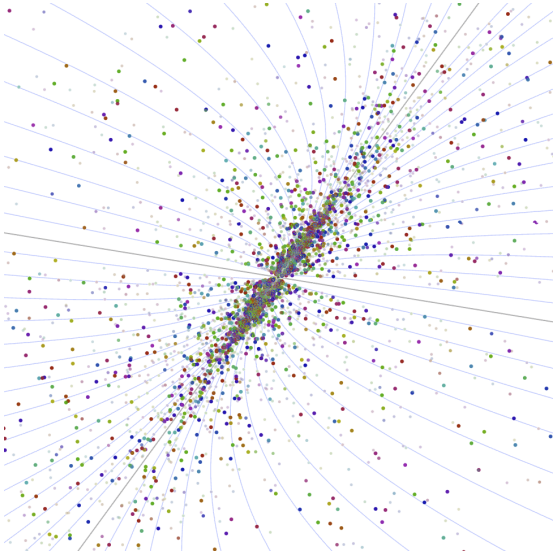
The "wave function" ψ_t (where t is the time parameter), in some number of variables: satisfies Schrodinger's equation for the system's Hamiltonian.

How to do computations:
The value of an observable A at time t is the inner product (like a dot product) of ψ_t with $A\psi_t$. This is actually given by an integral!

In this way, quantum mechanics relates to linear algebra.

Unfortunately: this part is beyond the scope of Math 1553.

Interactive Linear Algebra



Dan Margalit and Joe Rabinoff have written a free online textbook called *Interactive Linear Algebra*, with a version specifically created for this course.

`https://textbooks.math.gatech.edu/ila/1553/`

There are about 150 interactive demonstrations in the book. They're there for a reason: you'll be expected to gain and demonstrate a **geometric** understanding of the material.

How to Succeed in this Course

- Practice, practice, practice! It makes sense to most people that if you want to get good at tennis, you have to hit a million forehands and backhands. But for some reason, many people think you're either born good at math, or you're not. This is ridiculous. People who are good at math are just people who have spent a long time thinking about math. *Nobody* is born good at math.

Not good at math $\longrightarrow$

- Do the homework carefully. Homework is practice for the quizzes. Quizzes are practice for the midterms. Remember what I said about practice?
- Study the pictures. I expect you to play around with the demos in the book until you understand them!
- Take advantage of the resources provided. Come to office hours! Read the textbook! Go to Math Lab!

Course Administration

- Lecture slides are on the website before lecture. You can print them out and take notes.
- Homework is on WeBWorK (access through Canvas), and is due *Thursdays at 11:59pm* (except homework 0, due Friday).
- Quizzes happen in recitation most weeks.
- Piazza polls measure class participation. Sign up for Piazza through Canvas, *with your Canvas email address*. It's easiest if you then download the Piazza app on your phone.
- Exams: there are three midterms, and a cumulative final.

Questions?

Everything is on the course web page.

Resources

Everything is on the course web page.

Including these slides. There's a link from Canvas.

On the webpage and our lecture's calendar you'll find:

- The textbook: Interactive Linear Algebra is online-only.
- Course materials: lecture slides, practice exams, worksheet solutions, etc.
- Course administration: the names of your TAs, their office hours, your recitation location, etc.
- Course organization: grading policies, details about homework and exams, etc.
- Help and advice: how to succeed in this course, resources available to you.
- Calendar: what will happen on which day, when the midterms are, etc.

Canvas: your grades, links to Piazza and WeBWorK, announcements.

Piazza: this is where to ask questions.

WeBWorK: our online homework system.